Disney Monorail Project

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***ABSTRACT* — The objective of this project is to identify and test a non-contact type sensor technology to provide more dependable and reliable operation of the Walt Disney World monorail system. The solution is expected to improve accuracy and cost effectiveness with respect to maintenance and performance. The group chose this project as our senior design project because we feel we can provide a good mix of electrical and computer engineering skills to formulate a solution for Walt Disney World.**

***Index Terms* — Ultrasonic sensing technology, non-contact sensor.**

I. Introduction

The Walt Disney World Monorail System is a key part of the property's transportation system. It routinely carries over 100,000 passenger trips per day. The trains must operate reliably to insure this level of service. The system includes 12 Monorail Trains that operate over 14 lane-miles of elevated beamway, connecting the Magic Kingdom, Epcot, Ticket and Transportation Center, and three resort hotels.

Fig. 1. Monorail at Walt Disney World

To ensure safe and smooth service for its customers, the Walt Disney World Monorail Trains employ a mechanical "beam contact switch" to detect deflections between the train structure and the monorail beamway. The existing switches are mechanical wand-type switches. If the train suspension or tires are not in optimum condition, the wand will contact the monorail beamway and signal the system. There are several of these switches on each train. The existing switches are a high-maintenance item, and may also cause false alarms. There is a need to replace these switches with a system that will be both more reliable and lower in total operating and maintenance cost. There are lots of new and advanced technologies for non-contact available in the market, such as ultrasonic, microwave, photoelectric, magnetic, capacitive and inductive sensor technologies etc. Different types of technology are used in a variety of applications. The biggest challenge of this project is to determine which sensing technology fits the needs of this project.

The prototype is funded by Walt Disney World Design and Engineering. The prototype budget is $1500, including buying materials to build the prototype for testing.

II. Monorail profile

A. Monorail Train Description

The Mark VI train bodies are constructed of honeycomb, bonded aluminum or nomex panels. Propulsion for the trains is provided by eight, 100 horsepower (HP), and 600 VDC General Electric transit-type "cam" controllers. Braking is accomplished in two modes: dynamic and hydraulic disk. Air/hydraulic disk brakes are located on each primary load wheel. These hydraulic brakes are combined by the operator's controller with dynamic braking at approximately 7 mph, and serve to assist in the final deceleration of the train, as well as maintaining position at stations.

Primary suspension of the monorail vehicles is provided by pneumatically inflated rubber tires, operating in-line atop the beamway. Roll suspension and steering is provided by pneumatic type side tires, which operate horizontally on the sides of the beamway. Vehicles are suspended above each load tire by air bag springs, which automatically inflate or deflate to adjust for varying passenger load conditions.

The WALT DISNEY WORLD Resort monorail system, which has been in operation since 1971, currently has 12 Mark VI monorail trains that can operate at speeds of up to 45 mph. Each six-car train is 203.5 feet long and can carry more than 300 passengers. The WDW monorail beamway (track) covers nearly 14 miles, connecting the Magic Kingdom, Epcot, Ticket

and Transportation Center, and three resort hotels. The monorails routinely carry over 100,000 passengers a day.

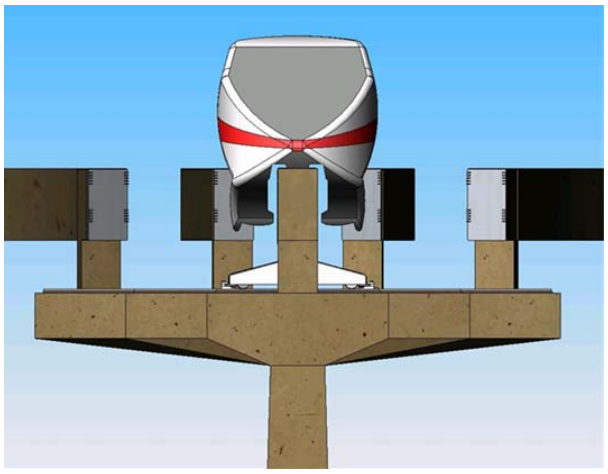

Fig. 2. Simulation of a Snapshot of the Front Side of a Monorail

B. Monorail Beamway Description

The monorail beamway is designed to supporting prestresed or post-tensioned continuous beams that are regularly 110 feet long. The monorail beamway is built about 60 feet off the ground. The beamway is about twenty-six inches wide and forty-eight inches high at the beam midsection. Figure 3 shows the dimension of the monorail beamway and the clearance outline. Because it is made of concrete and metal, the beamway would expand or shrink proportionally to temperature variation. Concrete has a linear expansion constant E_c = $12.0x10^{-6}{}^{o}C^{-1}$. The expanded or shrunken length can be calculated by the formula

$$L_N = L_0 * (1+ E_c * T) \quad (1)$$

In formula (1), E_c is the expansion coefficient, T is the temperature in degree Celsius, L_0 is the original length and L_N is the length under thermal interference. Since temperature variation can be huge between day and night time, the distance between the contact switches and the beamway may vary accordingly. Similarly, metal has a linear expansion constant E_M = $12.1x10^{-6}{}^{o}C^{-1}$. Same formula applies to length calculation under thermal interference.

1. Dimension of the beamway

The monorail beamway has about fourteen lane-miles long. It has a width of twenty-six inches, with two and a half between the surface of he beamway and underneath a monorail train. The train enters has the outline clearance of one hundred and twenty inches wide and ninety-three and a half tall. The figure below shows the dimension of the monorail beamway.

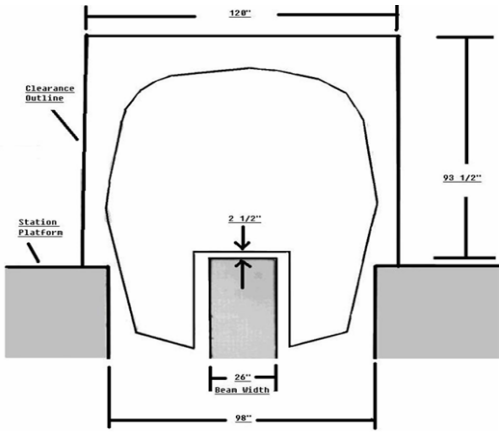

Fig. 3. The monorail beamway dimension and the clearance outline

2. Switch beam

Monorail trains switch from one beamway to the other. Therefore, this scenario has to be under consideration when a non-contact sensor is applied. First, the material of the monorail beamway is different, changing from concrete to metal. Second, the expansion coefficient of concrete is different from that of metal. The dimensions are therefore different, implying the transition point is not as smooth as the rest of beamway. The new design has to overcome this difficulty.

Obviously, changing the dimension of monorail beamway can significantly affect the precision of the contact switch. Therefore, a non-contact sensor solution is a perfect way to deal with this type of situation. It can be solved by pre-setting a safe range, rather than a specific length, so even though the length is expanded or shrunken thermally, as long as it falls in the range of a safe distance the monorail train system will run smoothly and perfectly.

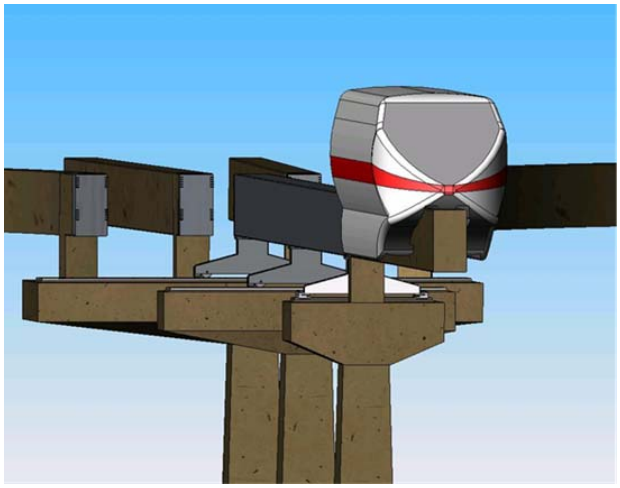

Fig. 4. Monorail changes route at the transition point

III. Problem Formulation

The objective of this senior design project is to research and recommend an alternative sensor technology that could perform similar functions as the existing sensor but with greater reliability and also cost lesser than the current system on maintenance. After analyzing the existing sensor system, several observations regarding the current system were obtained as described below:

- The exiting system is a beam contact switch that needs to be in contact with the monorail ensures a safe distance between the beamway and switches.
- The sensors are inexpensive but they are high maintenance items that need to be kept on optimum working condition for them to work.
- The switches are not very reliable and raise many false alarms during their working even when the monorails are function properly.

A. Requirements of the new sensor

Based on the interactions with the monorail technicians and engineers at Disney, a list of the requirements has been decided upon for the new sensor.

- The sensor needs to be resistant to high and low temperatures, it should work in the range of 0ºF to 155º F
- As few interferences as possible from dirt accumulating on sensor face
- Needs to work on a object that is moving, the monorail moves at a top speed of 40 mph
- The sensor should be able to operate correctly with vibration interference
- The sensor should be able to sense a minimum distance of 3 to 12 inches from the sensor face
- Relatively small in size, preferably no smaller than existing sensor which is approximately 3” x 8” x 3”
- Sensor must be able to work properly while getting wet.
- Sensor should not have a problem reflecting waves off of concrete or metal
- Sensor should not have a problem with the surface it is sensing changing color
- Needs to be able to work with different refractions (i.e. water on the beam)

IV. Ultrasonic Technology

After the research study, the group came up with a solution that ultrasonic sensing technology satisfies most of the needs. Ultrasonic sensors work on the principal that the system tries to detect the acoustic signals reflected off the target. The sensor consists of an ultrasonic transmitter that emits an ultrasonic pulse which is then reflected off a target. A wide-angle receiver tries to detect the received signal that is reflected off the target. The greatest advantage of the ultrasonic sensor is that the reflected acoustic signal is not dependant on the color of the reflecting material. Also the dust and other conditions will not affect the reflected signal and it is more accurate than other type of sensor. For example, in case of other sensors like photoelectric sensors dust could block the photoelectric receiver.

The critical specification for an ultrasonic sensor is the distance to which the sensor can work. If the measurement distance is too far the acoustic signal will be attenuated and dissipated before it reaches the receiver. Some of the other parameters that need to be considered are the receiver cone, which is the area where the receiver can receive the signal, the repeatability of the system that need to be check to see whether the sensor can display the same value for a length of time for the same distance. The accuracy of the system is also important to measure the value correctly.

A. Final Selection

The final selection sensor chosen is the Q45U Ultrasonic range finder developed by Banner Engineering Company. It satisfies most of the needs in this particular project.

1. Specification of Q45U

Some of the features of this ultrasonic sensor are [4]:

- Digital filtering for exceptional immunity to electrical and acoustic “noise”.
- Selectable 0 to 10V dc voltage sourcing or 4 to 20mA current sourcing analog outputs
- Selectable output slope: positive or negative with increasing target distance
- Wide operating temperature range of -25° to +70°C; all models include temperature compensation
- Rugged design for use in demanding sensing environments; rated IEC IP67, NEMA 6P

2. Dimension of Q45U

Q45U ultrasonic range finder fits the requirement of the project. In figure below, it shows the dimension of this sensor.

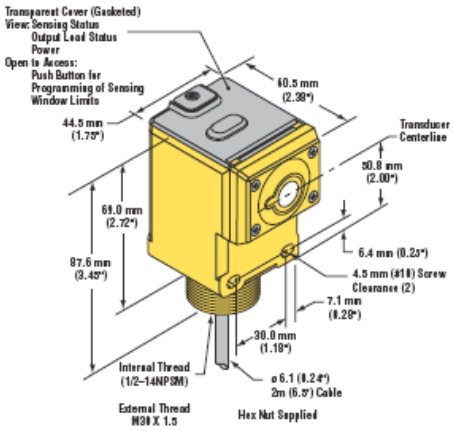

Fig. 5: Dimension of Q45U Ultrasonic Range finder

V. DESIGN

A better approach to make the new system more cost effective in terms of its maintenance time and cost efficiency is to use two sensors on each car for the new system instead of three sensors like the existing system. One sensor is to be located on one side, and the other sensor is on the top. Recalling from the previous sections, the side switch of the existing system is to ensure a minimum distance between the switch and the monorail beamway.

How this method is implemented is simple. It’s realizable that if the monorail train is leaning on one side, the distance between the monorail system and the beamway will be closer on that particular side. It also implies that the gap in between on the other side of the beamway is getting wider. Therefore, one sensor does the job for the both sides to lower the cost and maintenance time. Figure 6 shows a better idea how the new approach works.

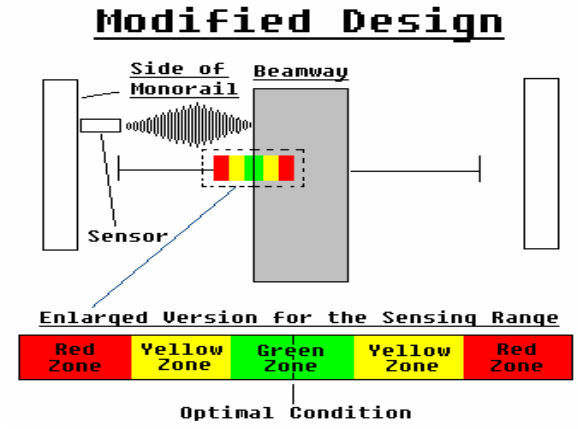

Fig. 6: Modified Design for the monorail train system

A double sensing range helps improve the overall system by reducing the number of sensors on each monorail train system. The new design is to have one green zone, two yellow zones and two red zones. “Green Zone” stands for the system is running smoothly. “Yellow Zone” represents the monorail train is getting closer to the beamway. Maintenance procedure might be needed. “Red Zone” means that the monorail train severely leans on either side of the monorail beamway. “The mid point of the green zone represents the monorail system maintaining in optimal condition. If the monorail train hits to the far left red zone, as in figure 7, it represents the train is leaning towards the left side of the beamway.

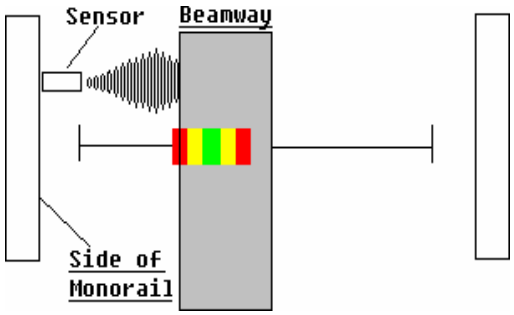

Fig. 7. The train is leaning towards the left side of the beamway

Similarly, the other extreme case is when the monorail train entering the red zone at the far right, which means that the train is leaning towards the right side of the monorail beamway. This situation is shown in Fig. 8.

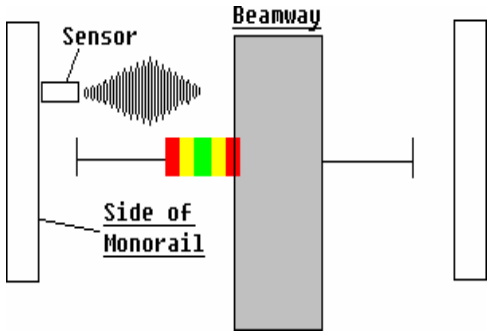

Fig. 8. The monorail train is severely leaning towards the right of the beamway

Similar solution can be seen for the side sensor to detect the distance between both sides. This is how one sensor can achieve both jobs.

VI. Microcontroller Components

The microcontroller that receives the data sent by the sensors and calculates if the distance between the monorail and the beamway is in correct range or if it needs to notify the pilot of the approaching of the monorail towards the beam, and the Graphical User Interface needed to display the distances and interact with the pilot of the monorail.

The other components, also referred as Modules, are: the CPU Module used to store and control the microcontroller, the Analog I/O Module to transform analog input to digital form, and the communication adapters & communication model to transfer data.

A. CPU Module

The CPU Module has a port 1, an RS232C port used to connect a laptop for example to download a program written in WindLDR, which comes with the CPU module, to accomplish data reading in to the microcontroller situated inside this Module.

This module also has cartridges connector allowing the chance to upgrade its performance by adding more memory chips to be able to store more operations or add another clock to synchronize components of this module. Figure 8 below, is the communication connector that allows the CPU module to be connected with a different module. The module also has a analog voltage input connector to be able to connect a analog voltage in the range of range 0 through 10 VDC; this voltage is converted in to a number that is stored in to a data register to so it is easier to use the input.

For the inputs, this module has an I/O terminal allowing the connection of inputs and outputs to the module. Another feature of this module is the power supply terminal allowing the connection of a power supply up to a value of 24DC.

The Expansion connector situated in upper corner of the module is used to connect the Analog to Digital I/O converter used to convert the analog inputs to digital form, explained later in the introduction to modules discussion.

This module also has the Light Emitted Diode (LED) making the readability of the module easier for the user, including a power led to see if the power is on or off, a Run led to determine if the module is running a program or not, an Error led informing the user of an error occurs in the execution of the program running or in the module it self, an Input led informing that a specific input is turned on and a Output led telling when a output is trigger.

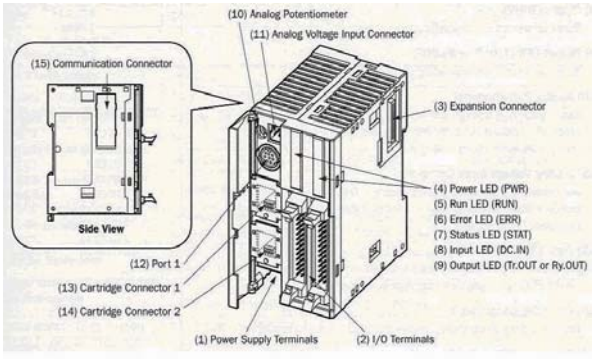

Fig. 8. This is the outlook for the CPU module

To be able to store data in the module, an Electrical Erasable Programmable Read Only Memory (EEPROM) was used. With a 32KB of memory the space available is good enough to store a couple of programs. If in case the storage capacity is not enough to store such big programs, this module would have the capability of upgrading the memory storage by adding a 64KB expansion cartridge in the specific slot in the CPU module.

The CPU module can handle up to seven additional modules, making it capable of expansion. Inside the CPU module there is also a Random Access Memory (RAM) used to make a back up of the data stored in EEPROM.

This backup will only remain for thirty minutes with a fully charged lithium battery. This battery can be recharged to its maximum capacity again after running out but it would take a day to be able to do that.

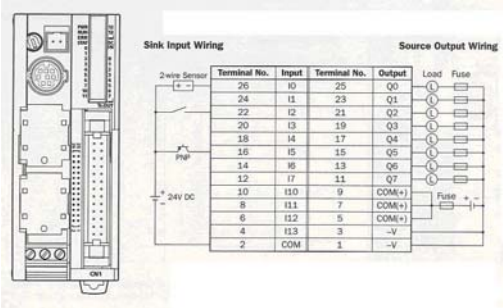
Sink Input Wiring
Source Output Wiring
2-wire Sensor
PNP
24V DC
Load
Fuse
Terminal No. | Input | Terminal No. | Output
26 | I0 | 25 | Q0
24 | I1 | 23 | Q1
22 | I2 | 21 | Q2
20 | I3 | 19 | Q3
18 | I4 | 17 | Q4
16 | I5 | 15 | Q5
14 | I6 | 13 | Q6
12 | I7 | 11 | Q7
10 | I10 | 9 | COM(+)
8 | I11 | 7 | COM(+)
6 | I12 | 5 | COM(+)
4 | I13 | 3 | -V
2 | COM | 1 | -V

Fig. 9. FCA-D20S3 CPU Module top view with Transistor Source Output

B. Analog I/O Module

The analog I/O module has fewer features from the CPU module, but it still has the expansion connectors. This allows the module to be connected to the CPU module and if necessary to other I/O modules since it has an Expansion Connectors on both sides.

It has Terminal Numbers for different inputs to be plugged in, and a cable terminal to connect wires to the module.

The Analog I/O module has a rated power voltage of 24V DC making it compatible with the CPU module that uses the same 24V for power. Even if this module has a voltage rating of twenty-four volts, the allowed range of operation is on a minimum of approximately twenty volts and a maximum of twenty-eight volts; The maximum allowed voltage can reach as high to twenty-eight volts since the voltage going into the module is not always twenty-four volts at all times.

The internal current draw is about 50mA. The input voltage for this module is in the range of a minimum from 0V to a maximum of 10V. The Analog I/O module has a sample time of a 20ms where the reading time is set; so for every 20ms it reads for the next set of values passed from the sensors to this particular module.

This module isolates the inputs between the power circuits. Figure 11 shows how the inputs are layout and where all the different connections can be made.

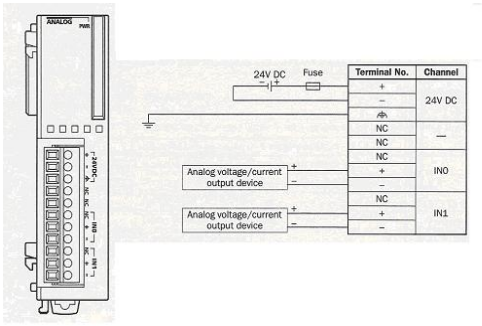

Fig. 10. Terminal of the analog I/O module display

This analog-to-digital-input-output converter has the capability of receiving a maximum of two inputs. The denomination of this outputs are IN0 (Input 0) for the first input and IN1 (Input 1) for the second input.

VII. LCD TOUCH SCREEN

The HG2F model is a 5.7" LCD touch screen with a resolution of 320x240 pixels with a maximum color pallet of 256 colors. The touch screen area is divided in to 192 regions making the screen able to handle up to 192 different areas to touch at one time. By analyzing the table the requirements for the screen regarding the project can by checked. As showed in the table below, the operational voltage is 24V making it compatible with the power supply needed for the modules that will be discussed in the next chapter. The operational temperature is consistent with the project having a range well over the normal temperature present in the location were the screen will be installed, since it will be in the car were the driver of the monorail is located.

Fig. 11. Appearance of HG2F LCD Touch Screen

A. Specification of HG2F LCD Touch Screen

	Item	Description
Electrical	Rated Voltage	24VDC
	Power consumption	10W maximum (at rated

		voltage)
	Momentary Power Interruption	10 msec
Environmental	Operation Temperature Range	0-50 °C
	Operation Humidity Range	30-85% RH
	Storage Temperature	-20 to 60 °C
	Storage Humidity	30-85% RH
	Degree of Protection	IP65
	Allowed Altitude	0-2000 m
Structural	Panel cutout Dimensions (W x H)	162.2mm x 126.5mm
	Exterior Dimension (W x H x D)	172mm x 136mm x 56mm
	Weight	Approx. 800g

VIII. SOFTWARE

The software to program the CPU module and the LCD touch screen are provided by the company. The figure below is a snap shot of the main screen of the GUI.

A. WINDLDR

The CPU model came with a software running on Windows called WINDLDR. This user-friendly program uses ladder logic which translate assembly language to a nice, clear and understanding code. Programs can be downloaded to the CPU module or upload to the computer bi-directionally. Online monitoring is provided to debug the program.

B. WINDOI-NV2

WINDOI-NV2 is the program used to program the LCD touch screen. The software provides different functionalities for communicating with the CPU module. Programs can be downloaded to the LCD module or upload to the computer bi-directionally. Simulation of the LCD touch screen is a way to debug when no CPU module is connected.

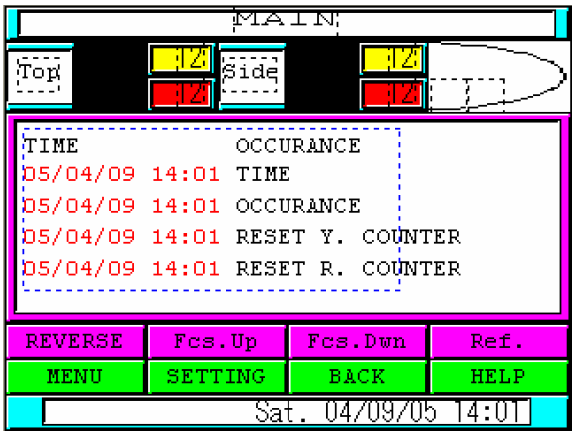

Fig. 12. Snap shot of the main screen of the GUI

IX. CONCLUSION

This two-semester long project is a valuable experience for the group in terms of how to work in group, how to conduct professional meetings and how to professionally write a technical report.

In the meetings, contributing ideas to the group, discussing various issues with engineers and going to the maintenance shop to investigate have given us valuable experience that never can be obtained from school. We also observe that the little pieces we have learned from engineering classes have become a big picture in reality. For example, in the physics study, we learned about the linear coefficient expansion of different type of materials, which is an issue to be considered when selecting a right sensor. We have to be precise on how the temperature is related to the dimension of the monorail beamway.

Moreover, it can be observed that different roles in the company have different responsibility. The management works conceptually on projects, yet the technicians have more first line information. For example, technicians working in the maintenance shop can locate the problems more deeply.

ACKNOWLEDGEMENT

During this project, the group gratefully appreciates the help of the following mentors and consultants for spending time with the group, guiding along and providing valuable information to help the group succeed in the project. We kindly thank for the help of the people: Dan Welsh, Jason Lovelace, Robert Shmerling, Bob Katz, Jeff McDonnough, and Leon Donovan

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Chun Sum Yeung, a senior student of the electrical engineering department at University of Central Florida, will start to pursue his master degree here at University of Central Florida after graduated in Summer 2005. He joined Research Experience for Undergraduates (REU), which funded by National Science Foundation, in Summer 2004, researching on robotics. He is a member of Tau Beta Pi and Golden Key.

Thomas Monetti, a senior student of the computer engineering department at University of Central Florida. Going to pursue a working career in the computer engineer profession and continue studies for master degree in business administration.

Wesley D. Deschaine is receiving his BSEE from University of Central Florida. He is presently working at Lockheed Martin Simulation, Training & Support, in the Components Engineering group. He will be starting classes towards his MSEE in the summer of 2005. His current research interests are in power semiconductors and device modeling. He is currently a student member of IEEE and PELS.